CHANGES IN HEALTH AND FITNESS IN FIREFIGHTER RECRUITS

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ABSTRACT

Kealey Jennings Wohlgemuth: Changes in Health and Fitness in Firefighter Recruits
(Under the direction of Eric D. Ryan)

The fire training academy prepares recruits for career firefighting, yet it is unknown how injury risk factors and predictors of performance change throughout the academy. The purpose of this study was to examine health, fitness, and simulated performance in firefighters across the academy. Nineteen recruits had their body composition, balance, movement quality, countermovement jump, cardiorespiratory fitness, upper and lower body strength, lower back endurance, and stair climb performance assessed at the beginning, middle, and end of the academy. The academy improved body composition, balance, cardiorespiratory fitness, leg extension strength, and stair climb performance ($P \leq 0.001 – 0.011$) across the academy. However, upper body strength and hamstrings-to-quadriceps ratio declined ($P \leq 0.001 – 0.010$) and movement quality, vertical jump performance, lower back endurance were unchanged ($P = 0.051 – 0.394$) across the academy. These findings highlight the positive effect of the academy on health and fitness variables, while identifying areas of improvement.

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LIST OF ABBREVIATIONS

1RM	One repetition maximum
BF	Body fat
BLS	Bureau of Labor Statistics
BM	Body mass
BMI	Body mass index
BP	Blood pressure
CAT	Candidate Aptitude Test
CHD	Coronary Heart Disease
CMJ	Countermovement jump
CPAT	Candidate Physical Ability Test
CRF	Cardiorespiratory fitness
CVD	Cardiovascular Disease
EMT	Emergency Medical Technician
ETT	Exercise tolerance testing
ETTT	Total treadmill time
FFM	Fat free mass
FM	Fat mass
FTO	Field Training Officer
HDL	High-density lipoproteins
HR	Heart rate
LB	Lower body
LE	Leg extension

LF	Leg flexion
LDL	Low-density lipoproteins
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Agency
NVFC	National Volunteer Fire Council
PA	Physical activity
PAT	Physical Ability Test
PF	Peak force
PL	Posterolateral
PM	Posteromedial
PT	Peak torque
PPA	Performance assessment
SOI	Survey of Occupational Injuries and Illnesses
TC	Total cholesterol
TG	Triglycerides
UB	Upper body
USFA	U.S. Fire Administration
VJ	Vertical jump
VO_2max	Maximal oxygen consumption
WAnT	Wingate anaerobic cycling test
WHR	Waist to hip ratio

CHAPTER I: INTRODUCTION

Firefighters are critical to public safety and respond to emergencies such as motor vehicle collisions, structure fires, and hazardous situations. In 2018, there were over one million firefighters in the United States, 370,000 of which were career firefighters, a 56% increase since 1986 (19). Although only 18% of departments include all or mostly career firefighter departments, they protect the majority (68%) of the U.S. population (19). Due to the dangerous tasks firefighters face as well as the long hours on duty during their 24-hour shifts, they experience some of the highest rates of occupational injuries (59). Per year, the estimated cost of firefighter injuries and prevention efforts is between $2.8 to $7.8 billion (11).

Previous literature has shown that firefighters experience a number of fatal and non-fatal injuries with estimates suggesting one injury occurring every eight minutes (26). Interestingly, many studies have shown that firefighters have the highest cardiovascular disease-related fatality rates of any public service occupational group (57) with ~40-50% of on-duty firefighter deaths being cardiovascular related in the past 10 years (54). Although fire-suppression activities represent a small percentage of total work time, there is a 10 to 100-fold increase in sudden cardiac death risk compared to nonemergency duties (32). Furthermore, Haynes et al. (25) has suggested there are 17-25 non-fatal cardiovascular-related events per sudden cardiac death. The most frequent on-duty non-fatal injuries include sprains and strains to the lower extremities and low back (30,34,59). These injuries are largely due to acute overexertion and slips, trips, and falls (5,34). These injuries although not fatal, are still debilitating and lead to above average worker's compensation claims, extended worker absence rates, and are the leading cause of early retirement (11,29,59). A number of previous studies have highlighted several health and fitness variables such as cardiorespiratory fitness, muscular power, muscular strength, muscular endurance, body composition, movement quality, balance, and lower back endurance as key injury risk factors for the primary fatal and non-fatal injuries in the fire service (9,10,14,40,42,46).

Although much of the time in the fire service is spent completing low-intensity (sedentary) tasks, firefighters are required to perform a variety of strenuous tasks such as climbing stairs, ladder extension, hose dragging, equipment carry, forcible entry, search and rescue, and ceiling breaching (2). Several studies show these activities result in significant physiological stress (41). For instance, during simulated tasks, firefighters demonstrated having high metabolic demands including increases in heart rate (95% of maximum), oxygen consumption (80% of maximum), plasma cortisol levels (133%), and core temperature (~1.68%) (44,45,55). Given the host of critical firefighter tasks are physically demanding, many previous studies have examined the influence of various health and fitness variables on performance during firefighting simulated tasks (10,42). Previous literature has shown that cardiorespiratory fitness, anaerobic fatigue resistance, body composition, muscular strength, and muscular endurance are related to firefighter performance (14,27,48,52,65).

The fire training academy is designed to prepare firefighters for the tasks seen on the job as well as prepare their bodies for the physical demands of the profession. The academy consists of both academic learning as well as practical skill training (67). Some of the skills individuals in the academy learn are fire behavior, construction, rescue, forcible entry, ladders, water supply, hoses, Hazmat, and pre-hospital care (67). The academy is also designed to improve overall health and fitness among the recruits to better prepare them for the rigors of being a firefighter.

For instance, Cornell et al (9) determined that over the course of a firefighter training academy (16 weeks), prospective firefighters were able to see positive changes in body composition, aerobic capacity, power, strength, and muscular endurance. Gnacinski et al. (22) also examined firefighter recruit estimated maximal oxygen consumption and heart rate recovery during the first, eighth, and sixteenth week of a 16 week academy. The recruits' estimated cardiorespiratory fitness improved during the beginning of academy training (16.5% increase estimated VO_2max and 12.8% greater change in heart rate recovery; week 1 to week 8); however, these specific variables plateaued during the last eight weeks of the academy (week 8 to week 16) (22).

To better understand how the firefighter training academy influences many of the key risk factors for the primary fatal and non-fatal firefighter injuries and predictors of firefighter performance, future work is needed to comprehensively examine these changes throughout the training academy. For example, as noted by Gnancinski et al. (22) it is possible that certain health or fitness variables may plateau or decrease from mid- to post-academy which may inform future academy training programs. Thus, the purpose of the present study was to examine health, fitness, and simulated performance in firefighter recruits at the beginning, mid-point, and end of the firefighter training academy.

Research Question

1. Does the firefighter training academy improve health and fitness variables (body composition, movement quality, balance, vertical jump, cardiorespiratory fitness, upper body isometric muscle strength, lower body isometric muscle strength, and lower back endurance) in firefighter recruits across the academy?

2. Does the firefighter training academy improve simulated task performance (stair climb time) in firefighter recruits across the academy?

<u>Research Hypotheses</u>

1. We hypothesized that the firefighter training academy will improve body composition, upper body isometric muscle strength, lower body isometric muscle strength, and lower back endurance across the academy (beginning < mid < end), while muscular power (vertical jump), cardiorespiratory fitness, movement quality, and balance will increase from the beginning of the academy to the midpoint and plateau (no significant change) from the midpoint to the end of the academy.
2. We hypothesized that the firefighter simulated task performance (stair climb time) will improve across the academy (beginning < mid < end).

<u>Study Impact</u>

The fire training academy is designed to prepare firefighters for tasks seen on the job as well as prepare their bodies for the physical demands of the profession through the process of academic learning as well as practical skill training. The proposed project comprehensively examined the influence of the fire academy on specific health and fitness variables previously identified as risk factors for the primary a) fatal and non-fatal injuries, and b) predictors of simulated firefighter performance across the fire academy. By determining changes at the beginning, mid, and end of the academy, these results may help future Fire Chiefs improve their current training strategies to ensure the academy is effectively targeting key injury risk factors and predictors of performance.

CHAPTER II: REVIEW OF LITERATURE

Background on the fire service

Evarts and Stein (2020) *US Fire Dept Profile 2018*

The purpose of this report was to provide an overview of fire departments, fire stations, career firefighters, and volunteer firefighters across the United States. Firefighters have many responsibilities and are vital to protecting the population as they suppress fires and offer emergency medical services. This report combines the National Fire Protection Agency (NFPA) Survey of Fire Departments for US Fire Experience During 2018 and the NFPA Fire Service Survey from 2016 to 2018. A total of 2,631 fire departments responded to the Survey of Fire Departments for US Fire Experience during 2018. This report shows that there are an estimated 1,115,000 career and volunteer firefighters in the United States in 2018, a 6% increase from 2017. Approximately 50% of firefighters range from 30 to 49 years old. In 2018, the surveys showed that there were 370,000 career firefighters with 4% being female, career firefighters. The surveys also showed that there were 29,705 fire departments in the United States with 18% of these fire departments being career or mostly career departments who protect 68% of the population. Career firefighters in this report were defined as individuals who are employed full-time by a fire department regardless of their position which can consist of inspection, prevention, suppression, and administrative roles. The report did not include federal, private, industrial, or military fire services. In 1986, there were only 237,750 career firefighters and 3,043 career departments; however, that number rose to 370,000 career firefighters and 5,377 career departments in 2018.

U.S. Fire Administration (2016) *Critical Health and Safety Issues in the Volunteer Fire Service*

The purpose of this report was to identify health and safety issues of the fire service and offer objectives, goals, and practices to improve the environment of the volunteer fire service. Firefighter injuries and deaths have been studied by the U.S. Fire Administration (USFA) and the National Volunteer Fire Council (NVFC) to identify firefighter health and safety trends in recent years. The findings from this report identified critical issues including the fire department culture, recruitment and retention, funding, the expanded role of firefighters, personal health, and safety protocols as major factors related to fire service health and safety.

According to the report, fire house culture can be harmful due to firefighters partaking in risk behaviors such as smoking, alcohol abuse, harassment, and misuse of departmental equipment. The authors explain that the fire service should work to have good behavior, public perception, and reflection of the profession; however, the recent report explains there are several issues within the fire house such as cheating on exams, arson, theft, misuse of facilities, and discrimination. The behaviors listed above can lead to unsafe fire houses and the authors explain that behaviors must change, beginning with management implementing rules and expectations to ensure safety of the firefighters.

Recruitment and retention are vital to the fire service as call volume has increased since 1980. The report explains that without proper staffing, firefighter operations and safety are at risk, especially as firefighters age and less individuals are filling vacant positions. To recruit and retain firefighters, they indicated that fire departments should be welcoming to recruits, women, and minorities to increase diversity within the fire service. The authors explain there are very few women and minorities in the fire service and that fire departments should prepare better recruitment strategies in hopes to increase staffing. Budgetary concerns are also listed as a key concern, with many fire departments, especially volunteer departments struggling financially. These shortfalls make it difficult to maintain buildings, vehicles, and rescue equipment. It is costly to recruit, provide training academies, and equipment to firefighters. Firefighter safety can be compromised if there are not adequate funds to supply necessary equipment. The authors explain that equipment can be old and sometimes, specifically in volunteer departments, not all the firefighters will have their own pieces of equipment, especially if expensive pieces of equipment such as self-contained breathing apparatuses. In addition to issues with recruitment and lack of funding discussed in the report, recently, firefighters have expanded their role of responding to structure fires and now respond to a plethora of calls such as terrorist attacks, explosions, and lost individuals. In 2015, there were more than 33.6 million fire department calls with only 1.3 million of these calls being fire-based. These many responsibilities increase injury risk and require additional training so that firefighters are adequately trained to respond to many emergencies.

Previous literature has shown that firefighters are at higher risk for disease and disorders, making personal health a priority of many fire departments. The report explains how the fire service is now focusing on mental, physical, and emotional health of firefighters through exercise and nutrition information. Not only can firefighters become injured on the job, but the stress of firefighting can induce depression and anxiety as firefighters must balance work schedules and unexpected calls with family life. Fire house culture and lack of funds also lead to unhealthy food choices for firefighters, which only increases the already high risk of firefighters becoming overweight, obese, and developing heart disease. In hopes of lowering the on-duty injuries and deaths, the authors explain how the NFPA has been implementing safety protocols through the use of codes and standards for firefighters, fire departments, and emergency response vehicles by providing standard operating procedures, personal protective equipment, self-contained breathing apparatuses, and operating guidelines for emergency vehicles. The authors explain that the Occupational Safety and Health Act of 1970 promotes health and safety within the fire service by having personal protective equipment for firefighters as well as continued training opportunities. The report also discusses the danger of responding to emergencies in fire trucks; however, in volunteer departments, firefighters are sometimes responding to an emergency in their personal vehicle. Volunteer departments have many standards to follow regarding safe driving, communication, and arrival to emergency scenes.

International Association of Fire Fighters (2007) *Candidate Physical Ability Test*

The purpose of the manual was to outline the Candidate Physical Ability Test (CPAT), a comprehensive tool used by fire departments to evaluate the physical ability of potential firefighters and examine their ability to complete job-related tasks. Firefighter recruits or candidates must have preparation sessions, orientation with, and practice trials (at least 2) of the CPAT prior to the official test. The CPAT includes eight tasks: stair climb, hose drag, equipment carry, ladder raise and extension, forcible entry, search, rescue, and ceiling breach and pull. The test is graded as a pass or fail and must be completed within 10 minutes and 20 seconds. During the CPAT, candidates wear a weighted vest (50lbs) to simulate the weight of a self-contained breathing apparatus and protective gear. Additionally, during the stair climb task, a further 25lbs of weight is used to simulate the high-rise pack (hose bundle).

Prior to beginning the test, the firefighter should be outfitted in long pants, a hard hat with fitted chin straps, gloves, and shoes with no open toe/heel. The test begins with the stair climb using the weighted vest and high-rise pack to simulate climbing stairs in full protective gear and carrying the hose bundle, which primarily challenges the cardiovascular system, lower body muscular endurance, and balance. Next, the candidates complete the hose drag using 200ft of double jacketed hose, an automatic nozzle, and two 55-gallon drums to simulate dragging a hose from the fire apparatus to where it is needed, challenging the firefighter's grip strength, upper body strength, and anaerobic endurance. Then, the equipment carry consists of carrying 2 saws for 75 feet to test the recruit's balance and grip strength. Event 4 is the ladder raise and extension which evaluates the firefighter's ability to place a ground ladder and extend the ladder to a roof/window using upper and lower body strength. The recruit will then move to the forcible entry simulation using a 10lb sledgehammer and forcible entry machine which acts as a measuring device to determine the force used to breach a wall or door. Next, the firefighter will complete the search simulation by crawling on their hands and knees through a 3-foot tunnel maze. Following the search, the firefighter will complete the rescue simulation by dragging a 165lb mannequin for 35 feet. Lastly, the firefighter will complete the ceiling breach and pull by using a pike pole to push up a hinged door and then hooking the device and pulling down with the pike. The test concludes when all events are completed, if the recruit runs out of time, or if a recruit fails an event. Failures vary per event; however, generally if the firefighter loses balances, drops equipment, steps outside of marked boxes, moves outside marked paths, fails to step on every step during the stair climb, does not touch each rung of the ladder during when raising it, or cannot finish an event, the event will be deemed a failure. Furthermore, by following the administration guidelines and event setup as outlined in the manual, the CPAT can be administered by many departments and training academies throughout the country. Environmental conditions should always be considered prior to beginning a CPAT to ensure safety of the candidates and tests should not be administered in extremely hot, cold, or wet environments. By administering practice sessions and tests according to the manual, biases can be eliminated and the CPAT can be consistent across the country.

Summary on the Background of the Fire Service

Today, the number of fire departments and the fire service are increasing steadily due to a larger population and growing cities. This growth has caused fire departments' responsibilities to extend beyond responding to structure fires, with many fire departments now responding to explosions, natural disasters, and water rescues. This extra workload can induce more stress that is already present in the fire service due to long working hours and time away from families. The additional responsibilities for firefighters contribute to injuries due to overexertion and overuse. Although the majority are non-fatal injuries, firefighters experience a high risk of fatal injuries and developing fatal diseases, such as cardiovascular disease, due to a lack of physical activity and poor dietary habits which are influenced by fire house culture. To prepare potential firefighters for their career, fire academies provide training and education prior to becoming a firefighter. During this training process, the CPAT is administered and must be passed by all potential firefighters to ensure individuals are physically capable of responding to emergencies.

Current health and fitness of the fire service

Storer, Dolezal, Abrazado, Smith, Batalin, Tseng, and Cooper (Journal of Strength and Conditioning Research 2014) *Firefighter Health and Fitness Assessment: A Call to Action*

The purpose of this investigation was to examine the current levels of fitness and cardiovascular disease (CVD) risk factors in firefighters compared to those reported in firefighters over the past 30 years. Fifty-one emergency responders (47 firefighters [career] and 4 command officers [1 fire chief and 3 battalion chiefs]) volunteered for the study. The study consisted of three visits on three separate days. On day one, participants completed health-related fitness tests: body composition (i.e., bioelectrical impedance analysis), isometric grip strength, abdominal endurance (i.e., curl-ups), upper body endurance (i.e., push-ups), core stability (i.e., plank), hamstring flexibility (i.e., sit-and-reach), and pulmonary function (i.e., spirometer). Day two consisted of the cardiopulmonary exercise test, an incremental walking or running protocol for 8-12 minutes on a treadmill to determine aerobic capacity (VO_2max). On day three, participants provided blood samples to examine total cholesterol, high-density lipoprotein, triglycerides, and glucose, which are markers of CVD risk.

For the results, the authors compared this cohort to previous literature (13 previous studies) in firefighters, as well as age and sex matched references values. The authors found similar values for isometric grip strength between this cohort (117kg), previously reported firefighters (112kg), and references values (110kg), as well as similar results for abdominal endurance among this study (47 curl-ups), previous firefighters (43 curl-ups), and references values (39 curl-ups). For upper body endurance, this study (37 push-ups) and previous literature (35 push-ups) exhibited greater values than reference value (16 push-ups), while for the sit-and-reach, this study showed the firefighters were less flexible (33cm) than previous literature

(34cm) and the references values (39cm). Although the results also show that aerobic capacity for the current cohort (39.6 ml/kg/min) was similar to reference values (40.4 ml/kg/min) and slightly greater than previous literature (36 ml/kg/min). However, these values still fall ~2.5 ml/kg/min below the recommended VO_2max values for firefighters (42 ml/kg/min). For CVD risk biomarkers, this cohort's results were similar to previous literature, and references values. Total cholesterol for this cohort (202 mg/dl) was similar to the published data (175 mg/dl), and references values (<200 mg/dl). Values were similar for this cohort (126 mg/dl, 55mg/dl), previous literature (101 mg/dl, 39mg/dl) and references values (<100 mg/dl, ≥ 40 mg/dl) for low-density lipoprotein cholesterol and high-density lipoprotein cholesterol, respectively. Lastly, the pulmonary function measured in forced vital capacity was similar across this study (95%), previous studies (103%), and reference values (100%). The authors (58) explain that the findings of this study demonstrate that current firefighters, even with improved efforts of training and standards, still have anthropometric, fitness, and cardiovascular disease risk indices similar to previous firefighters over the past 30 years. The results also emphasize the need for firefighter performance training aimed at improving strength, flexibility, and endurance, as well as reducing cardiovascular disease risk among the fire service, as it is reported that 70% of fire departments have no health and wellness programs (58).

Durand, Tsismenakis, Jahnke, Baur, Chrisophi, and Kales (Medicine & Science in Sports & Exercise 2011) *Firefighter's Physical Activity: Relation to Fitness and Cardiovascular Disease Risk*

The purpose of this study was to examine physical activity (PA) measures in structural firefighters and evaluate their relationships to cardiovascular disease (CVD) risk and cardiorespiratory fitness (CRF). For the study, 527 participants were obtained from the cohort study, "Predicting Cardiovascular Risk and Fitness in Firefighters." Firefighters self-reported

PA through a health and lifestyle questionnaire and the authors specifically quantified three dimensions of PA: frequency, duration, and intensity. To assess CRF, a maximal treadmill exercise test using the Bruce protocol evaluated oxygen consumption (i.e., METs) and total treadmill time (ETTT). Venous blood samples were taken to measure CVD risk by analyzing total cholesterol (TC), high-density lipoproteins (HDL), low-density lipoproteins (LDL), triglycerides (TG), glucose, and high-sensitivity C-reactive proteins.

The results showed that 49% of the cohort exercised three or less times per week, while 22% exercised five or more times per week. Also, approximately 47% of the firefighters exceeded 90 minutes of aerobic exercise per week; however, only 20% exercised for more than 150 minutes per week, indicating that many are not meeting the recommendations set forth by the Physical Activity Guidelines for Americans (70). The authors (16) explain that 37% of the firefighters did not obtain ≥12 METs , the number recommended by the National Fire Protection Agency to ensure firefighters have the exercise capacity to perform job-related duties. A greater CRF value was associated with all the higher categories of PA (frequency, duration, and intensity) when adjusted for BMI, age, and smoking status of the firefighters ($P < 0.001$). However, the results also show that increasing PA frequency during the week had the most improvements in many CVD risk factors (HDL [$P = 0.001$], TG [$P = 0.05$], TC/HDL [$P = 0.003$], and glucose [$P = 0.005$]). Lastly, firefighters in the highest BMI category (≥30 kg/m^2) exhibited poorer CRF and CVD risk factor values across all PA dimensions ($P < 0.001$). While all dimensions of PA are important, the authors (16) suggested that firefighters should partake in more frequent PA, especially aerobic PA, to improve CRF, CVD risk factors, and promote weight loss.

Sheaff, Bennett, Hanson, Kim, Hsu, Shim, Edwards, and Hurley (Journal of Strength and Conditioning Research 2010) *Physiological Determinants of the Candidate Physical Ability Test in Firefighters*

The purpose of this investigation was to examine the importance of physiological variables (i.e., muscular strength, muscular endurance, muscular power, anaerobic power, aerobic capacity) during the Candidate Physical Ability Test (CPAT) in firefighters. Thirty-three local career and volunteer firefighters completed five days of testing, with a minimum of one day of rest between visits. Day 1 consisted of a strength testing familiarization, a dual energy x-ray absorptiometry (DEXA) scan for body composition, and a graded treadmill exercise test to measure aerobic capacity (VO_2max). On day 2, firefighters completed assessments of one repetition maximum (1RM; knee extension, chest press, and leg press), muscle endurance (chest press and leg press), and knee extension muscle power. Day 3 consisted of hand function testing and isometric strength (fingertip force), in addition to a Wingate anaerobic cycling test (WAnT) to determine anaerobic power and fatigue index. On Day 4, firefighters completed an identical knee extension muscle power assessment and a weighted stair climb task to examine cardiovascular responses (i.e., heart rate, blood pressure). Lastly, on day 5, the firefighters performed the CPAT.

When participants were grouped based on passing or failing the CPAT, the results showed that WAnT peak power (watts/kg) and mean power (watts/sec) was 22% and 45% higher in firefighters who passed the CPAT, than the firefighters that failed ($P < 0.001$), respectively. Mean power relative to bodyweight during the WAnT (watts/sec/kg) was 25% greater in firefighters who passed the CPAT ($P < 0.001$), while absolute and relative VO_2max were 23% ($P < 0.001$) and 17% ($P < 0.01$) higher in firefighters who passed the CPAT, respectively.

However, upper and lower body strength, as well as percent body fat, were not significantly different between those who passed and failed the CPAT.

The relationships between each attribute (i.e., VO_2max, WAnT, muscle strength, muscle power, body composition, cardiovascular response to stair climb) and CPAT performance (i.e., time) were also determined. The mean power during WAnT had the strongest correlation (r = -0.66; $P < 0.001$) to CPAT time, while fatigue index during WAnT was also significantly related ($r = 0.559$; $P < 0.001$). In addition, finger isometric strength, upper body strength, maximal heart rate (HR) response to the stair climb, and absolute VO_2max (r = - 0.602 to 0.523; $P < 0.001$ to < 0.01) were also significantly related to CPAT performance. Lastly, the linear regression analysis showed that absolute VO_2max and fatigue index during the WAnT combined to predict CPAT performance time (Adj. $R^2 = 0.817$; $P < 0.001$), which suggests that aerobic capacity and anaerobic resistance to fatigue are important physiological variables for firefighter performance. Furthermore, improving the aforementioned variables should be the focus of training programs to refine firefighter performance by specifically enhancing cardiovascular responses to exercise, muscle strength, and muscle power.

Williford, Duey, Olson, Howard, and Wang (Ergonomics 1999) *Relationship between fire fighting suppression tasks and physical fitness*

The purpose of this study was to evaluate the relationship between fire suppression tasks and physical fitness parameters. Individual characteristics (i.e., height, weight, body fat percentage [%fat], resting blood pressure [BP], resting heart rate [HR]) and physical performance variables (i.e., pull-ups and push-ups until exhaustion, sit-ups in 1 minute, sit and each, 1.5-mile run, grip strength) were assessed in 91 male firefighters. Participants also completed a simulated job performance assessment (PPA) in which they completed fire suppression tasks (i.e., stair climb with hose, hose hoist, forcible entry, hose advance, victim rescue). Prior to the PPA, participants could attend practice sessions for six weeks with all participants required to complete at least one practice session. During the PPA, firefighters wore protective gear, a Polar heart rate monitor, and a self-contained breathing apparatus that was used throughout the PPA. Each task was individually timed, as well as the total time to complete the PPA.

The results showed significant correlations ($P < 0.01$) between total time to complete the PPA and several physical performance and characteristics such as grip strength, fat free weight, height, pull-ups, push-ups, 1.5-mile run, sit-ups, weight, and %fat ($r = -0.54$ to 0.38, $P < 0.01$). For example, a greater number of pull-ups completed and a shorter 1.5-mile run time was related to a shorter PPA completion time, suggesting that muscle strength and aerobic endurance are important to firefighting tasks. Additionally, the study showed that fat free weight, pull-ups, and 1.5-mile run time collectively best predicted firefighter job simulation performance ($r = 0.73$, $R^2 = 0.53$, SE = 96.18). The authors (65) suggest many physical performance and individual characteristic variables contribute to firefighter performance, specifically components such as muscle strength and aerobic endurance, which are vital to lifting heavy loads and moving efficiently on the fire ground. A majority of these variables can be improved through physical fitness training and conditioning, thus, by refining key physical performance variables and characteristics in firefighters, job performance could be improved.

Soteriades, Hauser, Kawachi, Liarokapis, Christiani, and Kales (Descriptive Epidemiology 2005). *Obesity and Cardiovascular Disease Risk Factors in Firefighters: A Prospective Cohort Study*

The purpose of this investigation was to evaluate the body mass index (BMI) of a cohort of firefighters, as well as examine the relationship between obesity and cardiovascular disease

(CVD) risk factors over the course of five years. The sample consisted of 270 firefighters that underwent BMI and CVD risk factor (i.e., blood pressure, blood glucose, lipids, smoking status) evaluation at baseline and at a five-year follow-up visit.

The results showed that obesity (BMI ≥30 kg/m^2; 27.1% to 29.0%; P < 0.0001), as well as extreme obesity (BMI ≥40 kg/m^2; 0.6% to 2.4%; P < 0.0001) increased from baseline to the five-year follow-up visit. When comparing CVD risk factors in obese and non-obese firefighters over the five-year period, firefighters who were obese were more likely to have hypertension than normal weight firefighters. Also, normal weight firefighters had 1.5 CVD risk factors, while obese firefighters had 1.8 (P = 0.90) and extremely obese firefighters had 2.1 CVD risk factors (P = 0.02). The linear mixed model analysis showed that firefighters gained an average of 1.15 pounds per year of active-duty firefighting across the five-year study (P < 0.0001), and when evaluating the association between years of duty and weight gain, weight was gained quicker in later years of duty when compared to baseline. The authors (56) explained that firefighters gained weight from baseline to the follow-up, while obesity increased from ~35 to 40%. Further, the obese firefighters exhibited a greater number of CVD risk factors. Health and body composition are declining as firefighters continue in their careers, which is not only an issue for the fire service, but also for long-term public health as obesity and cardiovascular disease are becoming more prevalent in society.

Szubert and Sobala (International Journal of Occupational Medicine and Environmental Health 2002) *Work-Related Injuries Among Firefighters: Sites and Circumstances of Their Occurrence*

The aim of this investigation was to assess injury causes, ratio (i.e., annual number of injuries per 1,000 workers), and duration of work disability due to on-duty injuries sustained in firefighters. The sample was gathered via stratified randomization, which consisted of 1,503 firefighters from 29 fire stations who were employed from 1994 to 1997. Strata were defined as fire stations A, B, C, or D based upon the number of firefighters at each station. Data were collected from personal records provided by the human resources department and work safety services. The research staff analyzed the cases of work disability and the number of days of work missed due to on-duty injuries, in addition to evaluating worker characteristics (i.e., firefighter age, work duration), and data regarding injuries during emergency response situations. Injuries that resulted in temporary disability for work were also evaluated for cause of injury.

The results showed that within the four years, 352 injuries occurred within 301 firefighters. The annual injury ratio was 70.3 injuries per 1,000 firefighters, with an average number of injury-related days lost of 293.7 days per 100 firefighters. Injuries that occurred during physical training resulted in 40% of all injuries and were responsible for 119.1 days of absence per 100 firefighters. The lowest number of injuries occurred in those who were 30 to 39 years, while the highest rate of injured firefighters were over 50 years. The most commonly reported injuries were dislocations, sprains, and strains of joints and muscles (34.1%) during firefighting operations, specifically with the highest rates of injuries to the legs (26%), ankles (19%), and feet (11%) during emergency operations. The authors (59) explain that most of the firefighter injuries occur during training (40%) and are responsible for 41% of absences at work. Most importantly, the results showed that the duration of work disability increased by 20% with increasing age of workers. In addition, the work hygiene and safety services discovered that over half of the firefighter accidents resulted from carelessness and inappropriate behavior, resulting in injuries due to slips, falls, stumbles, or lost balance. Furthermore, many injuries occur in older firefighters, which results in longer absence from work and recovery times. This study demonstrates the need for preventive training for firefighters of all ages, but especially older age, that focuses on increasing the lower body strength and decreases the risk of slips, stumbles, and lost balance.

Jahnke, Poston, Haddock, and Jitnarian (Obesity 2013) *Obesity and Incident Injury Among Career Firefighters in the Central United States*

The purpose of the study was to assess obesity as a risk factor for injuries in firefighters by specifically examining relationships between musculoskeletal injuries and body composition, in addition to demographic variables, physical activity, and health behaviors. For this investigation, 347 male firefighters were evaluated at baseline and after 6 or 9 months, for the volunteer and career firefighters, respectively. The primary measures of the study were musculoskeletal injury data via an injury reporting system and body composition. Firefighters reported injury type and location, duty being performed when injured, and cause of injury. Body composition was assessed by body mass index, body fat percentage via bioelectrical impedance, and waist circumference. For secondary measures, the research staff analyzed questionnaires regarding physical activity levels, tobacco and alcohol use, sleep, and depression.

The results showed that the most reported injuries were dislocations, sprains, and strains (57.1%), followed by superficial injuries and open wounds (18.6%). Most of the injuries occurred during training (31.3%), on the fire ground (19.4%), and returning or responding to calls (19.4%). Musculoskeletal injuries increased from baseline to follow-up by 6.9% and body composition was a significant predictor of musculoskeletal injury. For example, obese firefighters (BMI $\geq$ 30 kg/m^2) were 5.2 times (95% CI = 1.1-23.4) more likely to have a musculoskeletal injury than normal weight firefighters, while firefighters deemed obese based on waist circumference (WC > 40 inches) were 2.8 times (95% CI = 1.2-6.4) more likely to have an injury than their normal weight counterparts. The authors (31) suggest the data shows 90 out of every 1,000 firefighters should expect to experience a musculoskeletal injury within a one-year period. This investigation highlights the poor body composition and high rates of obesity within the fire service. By implementing programs focusing on health, nutrition, and fitness, with a specific focus on improving body composition, firefighters could reduce their risk of injury.

Soteriades, Smith, Tsismenakis, Baur, and Kales (Cardiology in Review 2011) *Cardiovascular Disease in US Firefighters*

The purpose of this review was to offer insight regarding the hazards of firefighting and the prevalence of cardiovascular disease (CVD) within the fire service. This systematic review highlights many studies in firefighters (predominately male) evaluating CVD risk factors and epidemiology, in addition to providing recommendations for CVD prevention within the fire service.

Firefighters experience many acute and chronic physiological and psychological stressors due to the strenuous job duties, as well as rotating shift work. A few of the most detrimental aspects of the fire service is the physical inactivity of many firefighters, the sedentary periods spent at the fire department, and the lack of physical fitness mandates after being hired. Physically, firefighters' bodies are often stressed as they are exposed to acute strain (e.g., smoke, loud noise, workload of duty responsibilities) and chronic strain as a result of poor habits (e.g., diet, lack of physical activity, sleep deprivation).

Among firefighters, premature retirements due to heart disease and on-duty cardiovascular events primarily occur in those who have CVD risk factors, whether they have been diagnosed or are not yet recognized. Key risk factors for CVD and on-duty coronary heart disease (CHD) fatalities include smoking (OR = 8.6; 95% CI = 4.2-1.7), obesity (OR = 3.1; 95% CI = 1.5-6.6), and hypertension (OR = 12.0; 95% CI = 4.2-17). Other common risk factors within firefighting are dyslipidemia, diabetes, and high cholesterol (21); however, greater age has a significant relationship with CVD and mortality, which is important to note given that young firefighter recruits must meet physical and medical requirements, whereas older firefighters are rarely tested.

The review also discussed occupational epidemiology of CVD in the fire service by examining morbidity and mortality rates from CVD within firefighters. Surprisingly, the review explained that recent literature has not shown increased risk of CVD death. Firefighters' standardized mortality ratio is around 0.9, or 10% lower for CHD than the normal population (49), attributed to the "healthy worker effect", where the health benefits resulting from being occupationally active allow firefighters to feel healthier. However, on-duty CVD mortality is high in the fire service, with most deaths occurring during fire suppression tasks and 67 - 77% of CHD deaths occurring between noon and midnight (32,33).

To manage CVD risk within the fire service, the authors (57) explain recruits should complete medical examinations (i.e., body composition, blood pressure, lipids, glucose), assess lifestyle habits (i.e., tobacco, diet, sleep, exercise), and perform physical abilities testing, while veteran firefighters should be medically examined regularly to evaluate their ability to complete job-related duties. Fire departments could also implement fitness and wellness initiatives through education and promoting diet and exercise programs. Furthermore, the authors suggest to determine risk by mandating maximal exercise tolerance testing (ETT) with an electrocardiogram for all firefighters over the age of 45, over the age of 35 in those who have known CVD risk factors, and when returning to duty. The authors (57) hypothesize that utilizing ETT to evaluate cardiorespiratory fitness will help predict mortality and morbidity.

Kales, Soteriades, Christophi, and Christiani (The New England Journal of Medicine 2007)
Emergency Duties and Deaths from Heart Disease among Firefighters in the United States

The purpose of this study was to examine duty-specific risk factors that led to on-duty deaths from coronary heart disease (CHD) in firefighters within the United States from 1994 to 2004. Specifically, the authors considered deaths related to alarm response, fire suppression, and physical training (e.g., fitness activities, ability testing, simulated drills). Furthermore, they also compared time spent performing firefighter duties between municipal departments, metropolitan departments, and a national database. The research staff analyzed public summaries from the U.S. Fire Administration regarding all deaths from January 1994 to December 2004 that occurred while on-duty and were classified as deaths due to CHD. Firefighter characteristics (i.e., age, sex, job status, fire department), death description (i.e., date, cause, mechanism), and duty performed (i.e., fire suppression, alarm response, alarm return, physical training, emergency medical service, rescue, nonfire emergency) were collected.

The results showed there were 1,144 deaths, with 449 due to CHD (39%). Upon further analysis of only the CHD-related deaths, 138 (31%) occurred during alarm response or return, 144 (32%) occurred during fire suppression, and 167 (37%) occurred during other duties. Although 32% of deaths occurred during fire suppression, these tasks only account for 1 to 5% of time on duty per year. Odds ratios and confidence intervals were used based on municipal, metropolitan, and national firefighter data to examine deaths due to CHD. The results showed that firefighters were 12.1 (95% CI = 9.0-16.4; $P < 0.001$) to 136.0 (95% CI = 101.0-183.0; $P < 0.001$) times more likely to die during fire suppression. Other emergency duties also increased the risk of death, specifically alarm response and alarm return which were 2.8 (95% CI = 1.9-4.0; $P < 0.001$) to 14.1 (95% CI = 9.8-20.3; $P < 0.001$) and 2.2 (95% CI = 1.6-3.1; $P < 0.001$) to 10.5 (95% CI = 7.5-14.7; $P < 0.001$) times more likely, respectively. Risk was also increased 2.9

(95% CI = 2.0-4.2; $P < 0.001$) to 6.6 (95% CI = 4.6-9.5; $P < 0.001$) times during physical training. The authors (32) also explained that the risk of death from CHD increased with age for all types of duty. During fire suppression tasks, the risk of a cardiac event is elevated due to the physical inactivity and underlying risk factors (e.g., diagnosed CHD, undiagnosed cardiovascular disease) of firefighters, increasing the strain on their cardiovascular system. Increasing physical activity could decrease the potential risk of an adverse cardiac event occurring while firefighting.

Butry, Webb, Gilbert, and Taylor (National Institute of Standards and Technology 2019) *The Economics of Firefighter Injuries in the United States*

The purpose of the report was to summarize the literature regarding the economic costs associated with firefighter health and non-fatal injuries by comparing data from the National Fire Protection Association (NFPA), U.S. Fire Administration (USFA) National Fire Incident Reporting System (NFIRS), and the Bureau of Labor Statistics (BLS) Survey of Occupational Injuries and Illness (SOII). The majority of injuries reported were strains and sprains (NFPA, 52.6%; NFIRS, 31.0%; SOII, 53.0%), primarily due to overexertion (NFPA, 27.1%; NFIRS, 30.0%; SOII, 52.0%) and slips, trips, and falls (NFPA, 21%; SOII, 21%) (1,24,69). Additionally, NFIRS reports that surfaces that were uneven, slippery, or icy were are also a major cause of injury (1).

Injuries while on-duty result in workers' compensation claims, with the largest claims reported from motor vehicle incidents ($31,148), overexertion ($15,447), and slips, trips, or falls ($13,773) (62). The report also estimated that the total cost of firefighter injuries is between $4.0 billion and $11.1 billion annually (11). Not only do workers' compensation claims carry a significant financial cost, but departments also may have to pay legal fees, disability claims, liability insurance, and overcome workplace disruptions as a result of injuries that can negatively impact productivity. Based on a high estimate of total injury costs ($5.9 billion) and normalizing annual costs to departments, firefighters, and total calls, a firefighter injury leads to an approximate cost of $197,860 for the fire department, $5,412 for the firefighter, and $170 per call (19,24,68). Although the economic burden of injury is high due to the medical expenses and workers compensation, the poor quality of life post-injury for many firefighters is the most significant consequence. The authors (4) also note that the literature generally investigates injuries and illnesses on-duty; however, hardly any data regarding cancer, mental health, and other long term disorders as a result of fire exposure are available.

Summary on the Current Health and Fitness of the Fire Service

The fire service is plagued with physical inactivity and poor dietary habits, which contribute to the high prevalence of obesity and cardiovascular disease in firefighters. Previous literature has shown that firefighters exhibit poor cardiorespiratory fitness, body composition, and cardiovascular health, which can inhibit firefighter performance in simulated fire suppression tasks and the CPAT. Furthermore, many firefighters suffer from on-duty fatal and non-fatal injuries, which contribute to a high economic burden. Many studies promote increasing physical fitness training, as well as nutritional education, to improve cardiorespiratory fitness and body composition, and in turn, decreasing cardiovascular disease risk factors, musculoskeletal injury risk, and adverse cardiac events while on-duty.

Background on the fire academy

The Raleigh Fire Department (The City of Raleigh 2020) *Candidate Selection Procedures for Firefighter Applicants*

The purpose of this manual was to outline the requirements and screening process for firefighter candidates. Throughout the training process, firefighters learn technical knowledge regarding emergency medicine, hazardous materials, firefighting, and rescue. A vital piece of training is the Recruit Training Academy, a 32-week program that consists of classroom education, practical experience, physical fitness testing, and live fire situations. All recruits must maintain an average of 70% in the classroom instruction portion of the academy, or risk termination. An important part of the academy is the Emergency Medical Technician (EMT) training which lasts 10 weeks and consists of written and practical exams. Following, the recruits will complete 18 weeks of fire suppression and fire prevention training. To complete the academy, recruits must pass a written exam based on general knowledge, the Candidate Aptitude Test (CAT), as well as a physical agility test (PAT) in which each task (i.e., ladder raise, rescue drag, run, obstacle course run, stair climb with weighted vest) is scored by time (in seconds). Recruits can be disqualified by failing the CAT and/or failing the PAT by not meeting individual task time limits (e.g., ladder raise, 35sec; rescue, 60sec; run, 15min; obstacle course run, 4:15min; stair climb, 30 sec). Once a recruit has passed all sections of the academy, they become probationary firefighters for six months post-academy graduation.

Cooper, Dudas, Huber, Jordan, and Martin (UNLV Theses, Dissertations, Professional Paper, and Capstones 2008) *Recruit training academy Las Vegas Fire and Rescue*

The purpose of the report was to assess the Las Vegas Fire Training Academy in 2006 to 2007 and offer recommendations for improving the training program. To evaluate the academy, the research team conducted two surveys - one designed for recruits and another for fire captains. The surveys assessed the academy structure (i.e., training, trainers) and quality of firefighter being produced (i.e., skills taught) from the academy. The academy consists of a 20-week program covering classroom education, emergency training, field drills, wellness programs, and hazardous material training. Each year, there are three to four academies with approximately 20 recruits per class.

The results from the surveys showed that nearly 43% of recruits were concerned with field training officers (FTO's) and 55% recommended improvements for or replacements of the FTO's due to lack of consistency and experience within trainers. Many recruits (38%) also suggested that more experience was needed with live fire training and fireground tasks. Within the fire captains, 55% agreed that FTO's were unprofessional during the academy and 78% felt FTO's do not understand the needs of the fire stations. In addition, 87% of fire captains also expressed a lack of communication between fire stations and the academy. Lastly, 97% felt the academy was easy and 84% said recruits were not well prepared to enter the fire service. Both recruits and fire captains believed floor firefighters from within the station would be better fit to train within the recruit academy. To improve the academy, the research staff suggests having highly skilled firefighters provide training, including more duty-specific tasks, and pairing a career firefighter with a recruit during the probationary period. During the survey period, several concerns were announced: the recruits were not physically fit and lacked basic skills, some hires had previously failed the academies, and Las Vegas had a lower dropout rate than other academies. Furthermore, the authors (6) explain that a disconnect is evident between the academy and firefighters at the station. Having more skilled trainers in the academy could increase on-the-job task and skill training in recruits, in turn, better preparing new firefighters to serve the public and meet the needs of their respective fire stations.

Cornell, Gnacinski, Meyer, and Ebersole (Medicine & Science in Sports & Exercise 2017)
Changes in Health and Fitness in Firefighter Recruits: An Observational Cohort Study

The purpose of this investigation was to observe changes in firefighter recruit health and fitness over the course of the recruit academy and probationary period (38 weeks). Twenty-seven male firefighters volunteered for the study and completed 16 weeks of the academy, as well as 22 weeks of probationary firefighting. During the academy, recruits completed one to two hours a day of technical training, in addition to exercise (aerobic and resistance) training. The aerobic exercise program consisted of a 2.5-mile run, two or three times a week, with a stair climb being completed for 30 minutes on weeks with only two runs. For resistance training, the recruits completed both free weight and machine-based exercises, targeting the upper and lower body, (3 sets, 8-10 repetitions between 60% and 80% one repetition maximum [1RM]), two to three days a week. It is important to note that no formal exercise training program was prescribed following graduation from the academy. Data were collected at the beginning of the academy (week 1), end of the academy (week 14; testing at exactly 16 weeks was not feasible for the department), and at a follow-up post-probationary period graduation (week 38). Body composition (i.e., body mass, body mass index [BMI], waist to hip ratio [WHR], estimated body fat [BF], and estimated fat-free mass [FFM]) and aerobic capacity (i.e., estimated VO_2max, relative heart rate) were assessed. Also, muscular power (i.e., countermovement jump), upper and lower body muscular strength (i.e., handgrip, 1RM bench press, 1RM back squat), and muscular endurance (i.e., push-up maximum in two minutes, plank hold for 4 minutes maximum) were tested as they are commonly associated with firefighter performance.

The results showed that there was a significant and large effect of time on body composition ($F_{10,17}$ =30.390; $P < 0.001$; $\eta^2_p = 0.947$), aerobic capacity ($F_{6,21}$ =55.111; $P < 0.001$; $\eta^2_p = 0.940$), muscular power ($F_{8,17}$ =2.785; $P < 0.036$; $\eta^2_p = 0.567$), muscular strength ($F_{6,20}$ =34.908; $P < 0.001$; $\eta^2_p = 0.9413$), and muscular endurance ($F_{4,23}$ =25.983; $P < 0.001$; $\eta^2_p = 0.819$). Further analyses showed that body mass, WHR, BF, and relative HR decreased from week 1 to 14; however, FFM, estimated absolute VO_2max, relative VO_2max, 1RM bench press, push-ups, plank, and 1RM back squat increased from week 1 to 14. All variables of body composition, except for FFM, in addition to relative VO2max and relative HR, increased from week 14 to 38. From week 14 to 38, handgrip, push-ups, plank, and 1RM bench press decreased. Lastly, from week 1 to 38, CMJ velocity (muscular power) decreased. The authors (9) explain that many health and fitness variables improved during the academy; however, many of these adaptations were lost during the probationary firefighter period. To maintain health and fitness throughout a firefighter's career, fire departments should implement physical fitness programs for all levels of firefighters.

Gnacinski, Ebersole, Cornell, Mims, Zamzow, and Meyer (Work 2016) *Firefighters' cardiovascular health and fitness: An observation of adaptations that occur during firefighter training academies*

The purpose of this investigation was to 1) assess changes in firefighter recruits estimated maximal oxygen uptake (VO_2max), 2) evaluate changes in firefighter recruits' heart rate recovery (ΔHR), and 3) determine the relationship between estimated VO_2max and ΔHR over the course of the training academy. In addition to the cardiorespiratory-related measures listed above, the research team also analyzed body composition via a scale and skinfold calipers (i.e., weight [BW], body fat percent [BF%]). Forty-two firefighter recruits volunteered for the study while they completed a 16-week training academy. Data collection occurred during the first (T1), eighth (T2), and sixteenth week (T3) of the academy. To assess heart rate for VO_2max and ΔHR, the recruits completed the Forestry Step Test (step to 90 beats per minute for 5 minutes) while wearing a Polar heart rate monitor. To measure ΔHR, the recruits immediately sat on the step at the completion of the test and heart rate was recorded at 0, 15, and 60 seconds. The 0 and 60 heart rate measurements were used for calculating ΔHR ($\Delta HR = HR_0 - HR_{60}$). Estimated VO_2max was calculated using the 15-second post-step test heart rate.

The results showed a significant difference between T1 and T2 and T1 and T3 for both estimated VO2max and ΔHR ($P < 0.001$). No significant differences were seen between T2 and T3 for estimated VO2max or ΔHR. Specifically, the estimated VO_2max increased by 16.5% and ΔHR increased by 12.8% from T1 to T2. Mean body weight decreased from 87.81kg at T1 to 86.41kg at T3 ($P < 0.05$) as well as from 87.17kg at T2 to 86.41kg at T3 ($P < 0.05$) but the change was not significant between T1 (87.81kg) and T2 (87.17kg). For BF%, there was significant decrease from T1 (15.03%), to T2 (13.58%) and T3 (13.50%) ($P < 0.001$), but the change was not significant from T2 and T3 (P = 0.702). The Pearson product-moment correlations showed there were no significant relationships between estimated VO_2max and ΔHR. However, BW and ΔHR were associated at T1 ($r = -0.563$; $P < 0.01$) and BF% and estimated VO_2max were associated at all three time points ($r = -0.601$ to -0.542; $P < 0.01$). In summary, the authors found estimated VO_2max, ΔHR, and BF% improved within the first eight weeks in the academy, while a loss in BW occurred within the final eight weeks of the academy. Furthermore, while the present study showed firefighter training academies can improve health and fitness variables among recruits at various time intervals, the academy training program needs to be modified so that fitness and health can be improved throughout the course of the academy.

Summary of the Fire Academy

Before becoming a career firefighter, firefighters must complete the training academy and probationary period. The academy consists of a classroom education portion, as well as an on-the-job skill training period prior to six months as a probationary firefighter. During the academy, the physical fitness and fire suppression training induces improvements to health and fitness variables (i.e., body composition, aerobic capacity, muscular strength, power, muscular endurance); however, these adaptations are not maintained throughout the probationary period and may even begin to decline during the last few weeks of the academy.

CHAPTER III: METHODOLOGY

Participants

Nineteen male (n=18) and female (n=1) career firefighter recruits were recruited from a local fire training academy near the University of North Carolina at Chapel Hill for this project. All participants read and signed an informed consent document explaining the risks and benefits of participating in the study. Participants were also asked to complete a health history and exercise status questionnaire prior to participating in the study. Participants were medically cleared for participation in the training academy prior to laboratory testing.

A sample size was calculated using an *a prior* power analysis using values reported by a previous study examining changes in cardiorespiratory fitness (CRF) and muscular power in recruits over the course of a firefighter training academy (9). Using these effect sizes for CRF (1.17) and muscular power (0.37), we need a minimum of 3 – 14 participants to provide 80% at the 5% significance level for a one-way repeated measures analysis of variance (3 time points) using G*Power software.

Experimental Design

The participants completed three separate days of testing at the laboratory around the same time of day (± 2 hours). Participants arrived following an eight hour fast, refrained from exercise for 24 hours, and vigorous exercise for 48 hours outside of the fire academy. Also, participants refrained from consuming alcohol or caffeine eight hours prior to visiting the laboratory. The visits were scheduled around their academy training and included a testing visit occurring during the first week of the academy, at the midpoint of academy (three months into academy), and at the end of the academy (the last week of the academy). Upon arrival to the laboratory, participants read and signed an informed consent document, completed a health history questionnaire, had their body composition, movement quality, balance, vertical jump (VJ), CRF, upper body isometric muscle strength, lower body isometric muscle strength, lower back endurance, and a weighted and timed stair climb task assessed. A figure detailing the testing sequence can be found in Figure 1. Recruits were given a standardized breakfast shake (Carnation Breakfast Essentials Nutritional Drink: High Protein, Rich Milk Chocolate or Classic French Vanilla, 8 Fl Oz bottle) to consume following the VJ assessments to provide an additional rest time (~ 5 mins) prior to the CRF assessment during their laboratory visit. The order of testing was chosen to minimize the effect of each test on the subsequent assessments. All resting and lower exertion assessments were performed prior to those that were more demanding.

Body Composition

Body mass and height were measured using a calibrated clinical scale (seca 769, Hamburg, Germany). Body composition was assessed using a previously validated and reliable four-compartment (4C) model as described previously by Smith-Ryan et al. (53). The 4C model uses dual energy x-ray absorptiometry (DEXA) (Lunar iDXA, GE Healthcare, Chicago, IL, USA) and bioelectrical impedance analysis (BIA) (InBody USA, Beverly Hills, CA, USA). The Wang 4C model (63) was used to determine fat mass (FM), fat free mass (FFM), and percent body fat (%BF) from measures of body volume (BV) and bone mineral density (BMD) from the DEXA, in addition to total body water (TBW) from the BIA assessment (53,63).

Participants were asked to wear loose athletic clothing and were free of metals and jewelry prior to all body composition assessments. For the BIA assessment, participants removed their shoes and socks and stood as still as possible on the designated footprints (electrodes) with their hands firmly grasping the handles, with the thumbs on the electrodes and arms away from the body. For the DEXA scan, the participants were positioned in the supine position, centered on the DEXA bed according to the manufacturer's guidelines. The DEXA estimations for FM, lean mass (LM), and BMD were used to estimate BV (53,63).

DEXA derived BV (53):

DEXA Volume (L) = (FM / 0.84) + (LM / 1.03) + (BMD / 11.63) + (- 3.12)

Four-compartment model (53,63):

FM (kg) = 2.748 (BV) – 0.699 (TBW) + 1.129 (BMD) – 2.051 (BM) ;

%BF = (FM / BM) x 100 ;

FFM (kg) = BM - FM

Modified Star Excursion Balance Test

Balance was assessed using the modified star excursion balance test, which has been shown to be a reliable and valid predictor of lower extremity injury risk and used previously in firefighters (10,23,43). Prior to the test, the administrator secured tape measures in the anterior, posteromedial, and posterolateral directions (i.e., straight ahead, backwards towards the opposite leg, and backwards away from the body, respectively) on the floor. The posteromedial and posterolateral tape measures were 135° from the anterior line. Participants stood with one foot at the center of the three lines and reached as far as possible with their non-weight bearing foot in the three directions. The participant touched the tape measure with their toe and the distance was recorded. Once the toe touched the tape, the participant returned to the center tape mark and placed both feet on the floor (28). Participants watched a demonstration of the correct movements and then completed three familiarization trials in each direction for both legs to minimize a learning effect (43). Participants kept the weight bearing foot firmly on the ground with their hands on their hips for the duration of each trial. Moving the weight bearing foot, losing balance, or removing the hands from the hips caused the participant to restart the trial. Three trials per leg were performed in all directions and the participant switched legs between each trial. The maximal reach distance in centimeters (cm) was normalized to leg length (distance in cm from anterior superior iliac spine to the distal medial malleolus) and analyzed. All trials were completed in athletic shoes on a non-slip surface.

Movement Quality

To assess lower extremity movement, participants performed three to five trials each of a double leg overhead squat as well as a single leg squat on each leg according to the guidelines provided by Fusionetics (Fusionetics, LLC, Milton, GA, USA) (7). For the double leg squat, participants stood with their feet shoulder width apart and their arms extended vertically above his or her head with the palms facing each other (18). The participant squatted to maximal, comfortable knee flexion and return to upright, starting position. One practice trial was used to familiarize the participants with the task. For the single leg squat, participants stood on the test foot with their toes facing forward, the non-weight bearing leg flexed 90° at the knee, 45° at the hip, and hands were placed on the hips with eyes looking forward (18). Instructions were to flex the weightbearing knee to a squat as long as it is comfortable and return to upright, starting position. A practice trial was also used to familiarize the participant with the movement. Movements were recorded with digital video (Samsung HMX-F90, Seoul, South Korea) and scored after testing. The double leg and single leg squats were analyzed with Fusionetics –

Human Performance System proprietary software and scored out of 100 with 100 being a perfect score and 0 being the poorest movement quality (7). Compensations made during the double leg and single leg squats were denoted for each participant (7). Each denotation was subtracted from 100 to determine each participant's score.

Countermovement Jump

Participants were asked to perform a no-step maximal countermovement vertical jump (VJ) as described previously (50). A Tendo Weightlifting Analyzer (Tendo Sports Machines, Trencin, Slovak Republic) and a jump mat (Just Jump or Run, Probotics, Inc., Huntsville, AL, USA) were used to measure average power (W) and jump height (cm). Participants were positioned with their feet shoulder width apart and their hands on their hips standing on the jump mat. A rapid descending squat movement was allowed prior to the rapid ascending jump. Participants were asked to jump with both feet at the same time and land in the same position. The Tendo Weightlifting Analyzer was used according to manufacturer's guidelines with the unit cord attached to a belt behind the participate slightly below the participant's umbilicus. The Tendo unit was placed on the floor behind them and allowed the cord to extend without impeding jumping technique. The jump mat measured jump height based on flight time which was the time between when the participant's feet left the mat and when their feet landed (50). The jump was repeated if both feet did not land at the same time or the same position. Three total jumps were completed, each separated by 30 seconds of rest. The jump with the highest jump height from all three jumps was used for analysis.

Cardiorespiratory Fitness

Maximal oxygen consumption (VO_2max) was estimated using a single-stage, treadmill (4FRONT, Woodway, Woodway USA, Inc., Waukesha, WI, USA) based submaximal cardiorespiratory assessment (17). Participants performed a four-minute warm-up prior to beginning the VO_2max assessment. Heart rate (HR) was monitored during the warm-up, VO_2max assessment, and cool down period using a Polar chest strap heart rate monitor and watch (Polar Electro, Lake Success, NY, USA) (17). The warm-up consisted of walking on the treadmill at a self-chosen speed between 3.22 to 7.24 kilometers per hour (2.0 to 4.5 miles per hour, respectively) at a 0% grade to elicit a HR within 50 to 70% of their age predicted HR maximum (HR max= 207 – 0.7 x age) (20). Following completion of the warm-up protocol, participants continued to walk at the same speed for four minutes at a 5% grade. Heart rate was recorded during the last 15 seconds of the last two minutes of the test (minute 3 and 4) and averaged to determine the final, average HR (15,17). A cool-down was completed at a 0% grade as the last stage of the CRF assessment. To estimate VO_2max, the following equation was used (17):

$$\begin{aligned} VO_2max = {} & 15.1 + 21.8 * \text{Speed (mph)} \\ & -0.327 * \text{Heart Rate (bpm)} \\ & -0.263 * \text{Speed} * \text{Age (year)} \\ & + 0.00504 * \text{Heart Rate} * \text{Age} \\ & + 5.98 * \text{Gender } (0 = \text{female}, 1 = \text{male}) \end{aligned}$$

Upper Body Strength

A custom-built, portable isometric dynamometer was used to assess upper body strength. Participants stood on aluminum plate and held a metal bar that was attached to the plate at waist level and performed an upright row. The participants grasped the bar with pronated grip with arms and legs shoulder width apart. The chain length was adjusted to ensure the handle is two centimeters below the umbilicus of each participant. This was recorded so that the same setup was used for each testing session. After completing a warm-up, participants completed three maximal voluntary contractions (MVCs) with 90 seconds of rest between each MVC. Instructions were to pull "as hard and as fast as possible" for three to five seconds. Strong verbal encouragement was given throughout each MVC.

Lower Body Strength

Participants had peak torque (PT) of their dominant leg extensors and leg flexors assessed using a calibrated dynamometer (HUMAC Norm, Computer Sports Medicine Inc., Stoughton, MA, USA). Leg dominance was determined as the preferred foot to kick a soccer ball. Participants were seated in the dynamometer with the dominant knee flexed at 60° in reference to full extension as 0°. The lower leg was secured to the lever arm of the dynamometer using a Velcro strap placed five centimeters proximal from the lateral malleolus of the participant's ankle. The dynamometer's axis of rotation was aligned with the center of the participant's dominant knee. Seatbelts were fastened across the participant's waist, contralateral limb, and chest to secure the torso. Arms were also crossed over the chest during the MVCs. Following a warm-up of three submaximal muscle actions (between 50 - 75% of perceived max), each participant performed an MVC. Participants were told to kick out (extension) or pull back (flexion) "as hard and as fast as possible." Each MVC was held for three to four seconds and strong verbal encouragement was given throughout each MVC. Participants completed two or three leg extension and flexion MVCs with each MVC separated with 90 seconds of rest. To assess injury risk (61,66), hamstrings-to-quadriceps ratio was also determined by dividing leg flexion MVC PT by leg extension MVC PT.

Signal Processing

Torque (Nm) was sampled at 2 kHz using a Biopac data acquisition system (MP150WSW; Biopac Systems, Inc., Goleta, CA, USA), accompanying Acknowledge software (Biopac System Inc., Goleta, CA, USA), and stored on a personal computer (ThinkPad T420; Lenovo, Morrisville, NC, USA). A custom-written software (LabVIEW 15; National Instruments, Austin, TX, USA) was used to process torque signals offline. All signals were corrected for baseline passive tension and filtered using a fourth order, zero phase shift low pass Butterworth filter with a 150 Hz cutoff frequency (60). Isometric peak torque was determined as the highest 500ms epoch for both leg flexion PT and leg extension PT as well as the highest 500ms epoch was used to determine upper body PF.

Lower Back Endurance

Participants performed a Modified Biering-Sorenson Test, which has been shown to be a reliable measure of lower back muscle endurance and predictor of low back dysfunction (3,38). Each participant was positioned prone in a horizontal Roman chair with the anterior superior iliac spines resting on the superior edge of the pelvic pad. Their hands were crossed in front of their chest and their ankles were secured under the ankle pad with their legs straight. Instructions were to bring their torso to parallel and maintain a horizontal position for as long as possible. The investigator started the timer as soon as the torso is horizontal and stopped the timer when the participant could no longer maintain the starting position. If the torso dropped below 10° of the horizontal position, one warning was given to regain horizontal position.

Stair Climb

To assess occupational performance, all participants performed a timed stair climb assessment as described previously (35). Prior to the stair climb, participants performed a warm-up by ascending 26 stairs once in athletic clothes and shoes (35). After the warm-up, the participants were outfitted with a 22.73kg weight vest (Z Fitness Inc., Sane Jose, CA, USA) positioned over the shoulders and on the chest to simulate the weight of a self-contained breathing apparatus (SCBA). The vest was secured against the body with Velcro straps to limit movement during the assessment and adjusted to fit comfortably. A verbal command signaled the start of the assessment and the start of timing. Beginning at the bottom of the stairs, the participants ascended and descended the stairs four times (stair height = 20cm) for a total 104 steps (35). Participants were asked to not use the handrails, unless they lost their balance during the assessment and each step was touched with one foot as quickly as possible. The stopwatch was stopped when both of the participant's feet touched the bottom of the stairs.

Statistical Analysis

All descriptive data was presented as the mean ± standard deviation (SD). Separate one-way repeated measures analysis of variance (ANOVA) analyses were used to determine potential changes in body composition (4C BF, 4C FM, 4C FFM, BM), movement quality, balance, VJ performance (average power, jump height), CRF, upper and lower body maximal strength, hamstrings-to-quadriceps ratio, lower back endurance, and the timed stair climb task. When appropriate, follow up analyses included Bonferroni post hoc pairwise comparisons. All statistical procedures were performed using SPSS version 26 (IBM; Chicago, IL, USA). An alpha level of $P \leq 0.05$ was set to determine statistical significance and partial eta (η^2) squared was used to examine effect size.

CHAPTER IV: MANUSCRIPT

Introduction

Firefighters are critical to public safety and respond to emergencies such as motor vehicle collisions, structure fires, and hazardous situations. In 2018, there were over 1 million firefighters in the United States, with 370,000 being career firefighters, which is a 56% increase since 1986 (19). Although only 18% of departments include all or mostly career firefighter departments, they protect the majority (68%) of the U.S. population (19). Due to the dangerous tasks firefighters face as well as the long hours on duty during their 24-hour shifts, they experience one of the highest rates of occupational injuries (59). Per year, the estimated cost of firefighter injuries and prevention efforts is between \$2.8 to \$7.8 billion (11).

Previous literature has shown that firefighters experience a number of fatal and non-fatal injuries with estimates suggesting 1 injury occurring every 8 minutes (26). Interestingly, many studies have shown that firefighters have the highest cardiovascular disease-related fatality rates of any public service occupational group (57) with ~40-50% of on-duty firefighter deaths being cardiovascular related in the past 10 years (54). Although fire-suppression activities represent a small percentage of total work time, there is a 10 to 100-fold increase in sudden cardiac death risk compared to nonemergency duties (32). Also, Haynes et al. (25) has suggested there are 17-25 non-fatal cardiovascular-related events per sudden cardiac death. The most frequent on-duty non-fatal injuries include sprains and strains to the lower extremities and low back (30,34,59). These injuries are largely due to acute overexertion and slips, trips, and falls (5,34) and lead to above average worker's compensation claims, extended worker absence rates, and are the leading cause of early retirement (11,29,59). A number of previous studies have highlighted several health and fitness variables such as cardiorespiratory fitness, muscular power, muscular strength, muscular endurance, body composition, movement quality, balance, and lower back endurance are key injury risk factors for the primary fatal and non-fatal injuries in the fire service (9,10,14,40,42,46).

Although much of the time in the fire service is spent completing low-intensity (sedentary) tasks, firefighters are required to perform a variety of strenuous tasks such as climbing stairs, ladder extension, hose dragging, equipment carry, forcible entry, search and rescue, and ceiling breaching (2). Several studies show these activities result in significant physiological stress (41). For instance, during simulated tasks, firefighters demonstrated having high metabolic demands including increases in heart rate (95% of maximum), oxygen consumption (80% of maximum), plasma cortisol levels (133%), and core temperature (~1.68%) (44,45,55). Given the host of critical firefighter tasks are physically demanding, many previous studies have examined the influence of various health and fitness variables on performance during firefighting simulated tasks (10,42). Previous literature has shown that cardiorespiratory fitness, anaerobic fatigue resistance, body composition, muscular strength, and muscular endurance are related to firefighter performance (14,27,48,52,65).

The fire training academy is designed to prepare firefighters for the tasks seen on the job as well as prepare their bodies for the physical demands of the profession. The academy consists of both academic learning as well as practical skill training (67) which often includes fire behavior, building construction, rescue, forcible entry, water management, hazardous materials, and pre-hospital care (67). The academy is also designed to improve the overall health and fitness among the recruits to better prepare them for the rigors of being a firefighter. For instance, Cornell et al (9) determined that over the course of a firefighter training academy (16 weeks), prospective firefighters were able to see positive changes in body composition, aerobic capacity, power, strength, and muscular endurance. Gnacinski et al. (22) also examined firefighter recruit estimated maximal oxygen consumption and heart rate recovery during the first, eighth, and sixteenth week of a 16 week academy. The recruits' estimated cardiorespiratory fitness improved during the beginning (from week 1 to 8) of academy training which included 16.5% and 12.8% increases in estimated VO_2max and in heart rate recovery, respectively). However, these specific variables plateaued during the last eight weeks of the academy (week 8 to week 16) (22).

To better understand how the firefighter training academy influences many of the key risk factors for the primary fatal and non-fatal firefighter injuries and predictors of firefighter performance, future work is needed to comprehensively examine these changes throughout the training academy. For example, as noted by Gnancinski et al. (22) it is possible that certain health or fitness variables may plateau or decrease from mid- to post-academy which may inform future academy training programs. Thus, the purpose of the present study is to examine health, fitness, and simulated performance in firefighter recruits at the beginning, mid-point, and end of the firefighter training academy.

Methods

Participants

Nineteen (1 female) career firefighter recruits (mean ± SD; age (yrs) 24.9 ± 4.3; stature (cm) 178.9 ± 7.63 body mass (kg) 82.8 ± 13.2; BMI (kg/m^2) 26.7 ± 3.1) were recruited from a local fire training academy. All participants read and signed an informed consent document (IRB #19-0943) explaining the risks and benefits of participating in the study. Participants were asked to complete a health history and exercise status questionnaire prior to participating in the study. All participants were medically cleared for participation in the training academy prior to laboratory testing.

A sample size was calculated using an *a prior* power analysis using values reported by a previous study examining changes in cardiorespiratory fitness (CRF) and muscular power in recruits over the course of a firefighter training academy (9). Using these effect sizes for CRF (1.17) and muscular power (0.37), we would need 3 – 14 participants to provide 80% power at the 5% significance level for a one-way repeated measures analysis of variance (3 time points) using G*Power software.

Experimental Design

The participants completed three separate days of testing at the laboratory around the same time of day (± 2 hours). Participants arrived following an eight hour fast and were asked to refrain from exercise for 24 hours, and vigorous exercise for 48 hours outside of the fire academy. Also, participants refrained from consuming alcohol or caffeine eight hours prior to visiting the laboratory. The visits were scheduled around their academy training and included a testing visit that occurred during the first week of the academy, at the midpoint of academy (three months into academy), and at the end of the academy (the last week of the academy). Upon arrival to the laboratory, participants read and signed an informed consent document, completed a health history questionnaire, had their body composition, movement quality, balance, vertical jump (VJ), cardiorespiratory fitness (CRF), upper body isometric muscle strength, lower body isometric muscle strength, lower back endurance, and a weighted and timed stair climb task assessed. A figure detailing the testing sequence can be found in Figure 1. Recruits were given a standardized breakfast shake (Carnation Breakfast Essentials Nutritional

Drink: High Protein, Rich Milk Chocolate or Classic French Vanilla, 8 Fl Oz bottle) to consume following the VJ assessments to provide an additional rest time (~ 5 mins) prior to the CRF assessment during their laboratory visit. The order of testing was chosen to minimize the effect of each test on the subsequent assessments. All resting and lower exertion assessments were performed prior to those that were more demanding.

Procedures

Body Composition

Body mass and height were measured using a calibrated clinical scale (seca 769, Hamburg, Germany). Body composition was assessed using a previously validated four-compartment (4C) model as described previously by Smith-Ryan et al. (53). The 4-C model uses a dual energy x-ray absorptiometry (DEXA) (Lunar iDXA, GE Healthcare, Chicago, IL, USA) and bioelectrical impedance analysis (BIA) (InBody USA, Beverly Hills, CA, USA). The Wang 4C model (63) was used to determine fat mass (FM), fat free mass (FFM), and percent body fat (%BF) from measures of body volume (BV) and bone mineral density (BMD) from the DEXA, in addition to total body water (TBW) from the BIA assessment (53,63).

Participants were asked to wear loose athletic clothing and were free of metal and jewelry prior to all body composition assessments. For the BIA assessment, participants removed their shoes and socks and stood as still as possible on the designated footprints (electrodes) with their hands firmly grasping the handles with the thumbs on the electrodes and arms away from the body. For the DEXA scan, the participants were positioned in the supine position, centered on the DEXA bed according to the manufacturer's guidelines. The DEXA estimations for FM, lean mass (LM), and BMD were used to estimate BV(53,63) (see below).

DEXA derived BV (53):

$$\text{DEXA Volume (L)} = (FM / 0.84) + (LM / 1.03) + (BMD / 11.63) + (-3.12)$$

Four-compartment model (53,63):

$$FM\ (kg) = 2.748\ (BV) - 0.699\ (TBW) + 1.129\ (BMD) - 2.051\ (BM)\ ;$$

$$\%BF = (FM / BM) \times 100\ ;$$

$$FFM\ (kg) = BM - FM$$

Modified Star Excursion Balance Test

Balance was assessed using the modified star excursion balance test, which has been shown to be a reliable and valid predictor of lower extremity injury risk and used previously in firefighters (10,23,43). Prior to the test, the administrator secured tape measures in the anterior, posteromedial, and posterolateral directions (i.e., straight ahead, backwards towards the opposite leg, and backwards away from the body, respectively) on the floor. The posteromedial and posterolateral tape measures were 135° from the anterior line. Participants stood with one foot at the center of the three lines and reached as far as possible with their non-weight bearing foot in the three directions. The participant touched the tape measure with their toe and the distance was recorded. Once the toe touched the tape, the participant returned to the center tape mark and placed both feet on the floor (28). Prior to testing, participants watched a demonstration of the correct movements and then completed three familiarization trials in each direction for both legs to minimize a learning effect (43). Participants kept the weight bearing foot firmly on the ground with their hands on their hips for the duration of each trial. Moving the weight bearing foot, losing balance, or removing the hands from the hips caused the participant to restart the trial. Three trials per leg were performed in all directions and the participant switched legs between each trial. The maximal reach distance in centimeters (cm) was normalized to dominant leg length (distance in cm from anterior superior iliac spine to the distal medial malleolus). All trials were completed in athletic shoes on a non-slip surface.

Movement Quality

To assess lower extremity movement quality, participants performed three to five trials each of a double leg overhead squat as well as a single leg squat on each leg according to the guidelines provided by Fusionetics (Fusionetics, LLC, Milton, GA, USA) (7). For the double leg squat, participants stood with their feet shoulder width apart and their arms extended vertically above their head with their palms facing each other (18). The participant performed a squat to maximal, comfortable knee flexion and then returned to the upright, starting position. One practice trial was used to familiarize the participants with the task. For the single leg squat, participants stood on the test foot with their toes facing forward, the non-weight bearing leg flexed 90° at the knee, 45° at the hip, and their hands placed on the hips with their eyes looking forward (18). Instructions were to flex the weightbearing knee to a comfortable squat position and return to the upright starting position. A practice trial was provided for all participants to familiarize them with the movement. Movements were recorded with digital video (Samsung HMX-F90, Seoul, South Korea) and scored after testing. The double leg and single leg squats were analyzed with Fusionetics – Human Performance System proprietary software and scored out of 100 with 100 being a perfect score and 0 being the poorest movement quality (7). Compensations made during the double leg and single leg squats were denoted for each participant (7). Each denotation was subtracted from 100 to determine each participant's score.

Countermovement Jump

Participants were asked to perform a no-step maximal countermovement vertical jump (VJ) as described previously (50). A Tendo Weightlifting Analyzer (Tendo Sports Machines, Trencin, Slovak Republic) and a jump mat (Just Jump or Run, Probotics, Inc., Huntsville, AL, USA) were used to measure average power (W) and jump height (cm). Participants were positioned with their feet shoulder width apart and their hands on their hips standing on the jump mat. A rapid descending squat movement was allowed prior to the rapid ascending jump. Participants were asked to jump with both feet at the same time and land in the same position. The Tendo Weightlifting Analyzer was used according to manufacturer's guidelines with the unit cord attached to a belt behind the participate slightly below the participant's umbilicus. The Tendo unit was placed on the floor behind them and allowed the cord to extend without impeding jumping technique. The jump mat measured jump height based on flight time which is the time between when the participant's feet left the mat and when their feet landed (50). The jump was repeated if both feet do not land at the same time or the same position. Three total jumps were completed, each separated by 30 seconds of rest. The jump with the highest jump height from all three jumps was used for analysis.

Cardiorespiratory Fitness

Maximal oxygen consumption (VO_2max) was estimated using a single-stage, treadmill (4FRONT, Woodway, Woodway USA, Inc., Waukesha, WI, USA) based submaximal CRF assessment (17). Participants performed a four-minute warm-up prior to beginning the VO_2max assessment. Heart rate (HR) was monitored during the warm-up, VO_2max assessment, and cool down period using a Polar chest strap heart rate monitor and watch (Polar Electro, Lake Success, NY, USA) (17). The warm-up consisted of walking on the treadmill at a self-chosen speed between 3.22 to 7.24 kilometers per hour (2.0 to 4.5 miles per hour, respectively) at a 0% grade to elicit a HR within 50 to 70% of their age predicted HR maximum (HR max= 207 – 0.7 x age) (20). Following completion of the warm-up protocol, participants continued to walk at the same speed for four minutes at a 5% grade. Heart rate was recorded during the last 15 seconds of the last two minutes of the test (minute 3 and 4) and averaged to determine the final, average HR (15,17). A cool-down was completed at a 0% grade as the last stage of the CRF assessment. To estimate VO_2max, the following equation was used (17):

$$
\begin{aligned}
VO_2max = {} & 15.1 + 21.8 * \text{Speed (mph)} \\
& -0.327 * \text{Heart Rate (bpm)} \\
& -0.263 * \text{Speed} * \text{Age (year)} \\
& + 0.00504 * \text{Heart Rate} * \text{Age} \\
& + 5.98 * \text{Gender } (0 = \text{female}, 1 = \text{male})
\end{aligned}
$$

Upper Body Strength

A custom-built, portable isometric dynamometer was used to assess upper body strength. Participants stood on an aluminum plate and held a metal bar that was attached to the plate with a chain and an in-series tensiometer. The participants grasped the bar with a pronated grip with their arms and legs shoulder width apart. The chain length was adjusted to ensure the handle was two centimeters below the umbilicus of each participant prior to performing the upright row. This was recorded so that the same setup was used for each testing session. After completing a warm-up, participants completed three maximal voluntary contractions (MVCs) with 90 seconds of rest between each MVC. Instructions were to pull “as hard and as fast as possible” for three to five seconds. Strong verbal encouragement was given throughout each MVC.

Lower Body Strength

Isometric peak torque (PT) of the dominant leg extensors and leg flexors were assessed using a calibrated isokinetic dynamometer (HUMAC Norm, Computer Sports Medicine Inc., Stoughton, MA, USA). Leg dominance was determined as the preferred foot to kick a soccer ball. Participants were seated in the dynamometer with the dominant knee flexed at 60° (full extension = 0°). The lower leg was secured to the lever arm of the dynamometer using a Velcro strap placed five centimeters proximal from the lateral malleolus of the participant’s ankle. The dynamometer’s axis of rotation was aligned with the center of the participant’s dominant knee. Seatbelts were fastened across the participant’s waist, contralateral limb, and chest to secure the torso. Arms were also crossed over the chest during the MVCs. Prior to performing the MVCs, a warm-up of three submaximal muscle actions (between 50 - 75% of perceived max) were performed. Participants were told to kick out (extension) or pull back (flexion) “as hard and as fast as possible.” Each MVC was held for three to four seconds and strong verbal encouragement was given throughout each MVC. Participants completed two to three leg extension and flexion MVCs separated by 90 seconds of rest. To assess lower body injury risk (61,66), the hamstrings-to-quadriceps (H:Q) ratio was also determined by diving leg flexion MVC PT by leg extension MVC PT.

Signal Processing

Torque (Nm) was sampled at 2 kHz using a Biopac data acquisition system (MP150WSW; Biopac Systems, Inc., Goleta, CA, USA), accompanying Acknowledge software (Biopac System Inc., Goleta, CA, USA), and stored on a personal computer (ThinkPad T420;

Lenovo, Morrisville, NC, USA). A custom-written software (LabVIEW 15; National Instruments, Austin, TX, USA) was used to process torque signals offline. All signals were corrected for baseline passive tension and filtered using a fourth order, zero phase shift low pass Butterworth filter with a 150 Hz cutoff frequency (60). Isometric PT was determined as the highest 500ms epoch for all strength measures.

Lower Back Endurance

Participants performed a Modified Biering-Sorenson Test, which has been shown to be a reliable measure of lower back muscle endurance and predictor of low back dysfunction (3,38). Each participant was positioned prone in a horizontal Roman chair with the anterior superior iliac spines resting on the superior edge of the pelvic pad. Their hands were crossed in front of their chest and their ankles were secured under the ankle pad with their legs straight. Participants were asked to bring their torso to parallel and maintain a horizontal position for as long as possible. The investigator started the timer as soon as the torso was horizontal and stopped the timer when the participant could longer maintain the starting position. If the torso dropped below 10° of the horizontal position, one warning was given to regain horizontal position.

Stair Climb

To assess occupational performance, all participants performed a timed stair climb assessment as described previously (35). Prior to the stair climb, participants performed a warm-up by ascending 26 stairs once in athletic clothes and shoes (35). The participants were then outfitted with a 22.73kg weighted vest (Z Fitness Inc., Sane Jose, CA, USA) positioned over the shoulders and on the chest to simulate the weight of their personal protective equipment and self-contained breathing apparatus. The vest was secured against the body with Velcro straps to limit movement during the assessment and adjusted to fit comfortably. A verbal command signaled the start of the assessment and the start of timing. Participants ascended and descended the stairs four times (stair height = 18.5cm) for a total 104 steps (35). Participants were asked to not use the handrails, unless they lost their balance during the assessment and each step was touched with one foot as quickly as possible. The stopwatch was stopped when both of the participant's feet touched the bottom of the stairs.

Statistical Analysis

All descriptive data are presented as the mean ± standard deviation (SD). Separate one-way repeated measures analysis of variance (ANOVA) analyses were used to determine potential changes in body composition (4C BF, 4C FM, 4C FFM, BM), movement quality, balance, VJ performance (average power, jump height), CRF, upper and lower body maximal strength, H:Q ratio, lower back endurance, and the timed stair climb task during the training academy. When appropriate, follow up analyses included Bonferroni post hoc pairwise comparisons. All statistical procedures were performed using SPSS version 26 (IBM; Chicago, IL, USA). An alpha level of $P \leq 0.05$ was set to determine statistical significance and partial eta (η^2) squared was used to examine effect size.

Results

The mean ± SD values for all variables at each time point are presented in Table 1. Eighteen recruits completed all testing visits (n = 18); however, one recruit only completed the beginning and mid-testing sessions.

Body Composition

There were significant main effects for time for the 4C model for evaluating FM, FFM, and %BF ($P \leq 0.001$; $\eta^2 = 0.331 – 0.670$), however, there was no main effect for BM ($P = 0.576$;

$\eta^2 = 0.032$). The recruits FM and %BF was significantly lower at the end of the academy when compared to the beginning ($P = 0.009 – 0.027$) and midpoint ($P \leq 0.001$) of the academy, however, there was no significant difference between the beginning and the midpoint of the academy ($P > 0.999$). Additionally, FFM was greater at the end of the academy when compared to the beginning and midpoint of the academy ($P < 0.001$), however, there were no significant differences between the beginning and midpoint of the academy ($P = 0.071$).

Modified Star Excursion Balance Test

There was a significant main effect for time for the composite score, posteromedial reach, and posterolateral reach ($P = 0.006 – 0.011$; $\eta^2 = 0.234 – 0.259$), however, there was no main effect for the anterior reach ($P = 0.312$; $\eta^2 = 0.066$). The composite score and posteromedial reach increased from the beginning to the end of the academy ($P = 0.024 – 0.040$), however, there was no significant difference between midpoint and the beginning and end of the academy ($P \geq 0.061$). Further, posterolateral reach was greater at both the midpoint and the end of the academy ($P = 0.018 – 0.044$) when compared to the beginning of the academy, however, there was no significant difference between the midpoint and end of the academy ($P > 0.999$).

Movement Quality

There was no significant main effect for time for the movement quality score ($P = 0.051$; $\eta^2 = 0.161$).

Countermovement Jump

There was no main effect for time for average power and jump height ($P = 0.094 – 0.356$; $\eta^2 = 0.059 – 0.130$).

Cardiorespiratory Fitness

There was a significant main effect for time for estimated VO_2max ($P < 0.001$, $\eta^2 = 0.672$). Estimated VO_2max significantly increased from the beginning to the midpoint and end of the academy ($P < 0.001$), however, there was no significant difference between the midpoint and end of the academy ($P = 0.170$).

Upper Body Strength

There was a significant main effect for time for upper body PF ($P = 0.010$, $\eta^2 = 0.277$). Upper body PF was significantly less at the end of the academy than the beginning and midpoint of the academy ($P = 0.040 – 0.049$), however, there was no significant difference between the beginning and midpoint of the academy ($P = 0.986$).

Lower Body Strength

There was a significant main effect for time for leg extension PT, leg flexion PT, and H:Q ratio ($P \leq 0.027$; $\eta^2 = 0.225 – 0.466$). Leg extension PT significantly increased from the beginning to the end of the academy ($P = 0.012$), however, there was no significant difference between the midpoint and the beginning and end of the academy ($P \geq 0.087$). Leg flexion PT had no significant differences between time points ($P \geq 0.069$). Further, the H:Q ratio was significantly lower at both the midpoint and end of the academy when compared to the beginning of the academy ($P = 0.001 – 0.002$), however, there was no significant difference between the midpoint and end of the academy ($P = 0.658$).

Lower Back Endurance

There was no main effect for time for the lower back endurance ($P = 0.394$, $\eta^2 = 0.050$).

Stair Climb

There was a significant main effect for time for stair climb performance ($P < 0.001$; $\eta^2 = 0.487$). Stair climb performance was faster at both the midpoint and end of the academy (P = 0.001 – 0.002) when compared to the beginning, however, there was no significant difference between the midpoint and end of the academy (P = 0.233).

Discussion

The proposed project comprehensively examined the influence of the fire academy on specific health and fitness variables previously identified as risk factors for the primary fatal and non-fatal injuries in the fire service, and predictors of simulated firefighter performance at the beginning, midpoint, and end of the fire academy. The primary findings indicated that body composition, balance, CRF, LE strength, and stair climb performed improved across the training academy, however, UB PF and the H:Q ratio decreased across the academy. Lastly, movement quality, vertical jump performance, and lower back endurance were not significantly different across the academy.

Body Composition

The results of the current study indicated that despite no changes in BM across the academy, all body composition variables (FM, FFM, %BF) remained stable from the beginning to the midpoint of the academy followed by an increase in FFM and decrease in FM and %BF at the end of the academy. Previous studies have reported similar findings for changes in FFM and %BF, but differences in changes in body mass across the academy (9,37). For example, Cornell et al. (9) reported a 31% decrease in %BF, while Lan et al. (37) reported a negative slope (-0.8) for changes in %BF across the academy. Further, Cornell et al. (9) also reported an increase in estimated FFM (4%) across the academy. However, in contrast to our findings, Cornell et al.(9)

reported a decrease (3%) in body mass across the academy (9,37). The discrepancies in the change in body mass are unclear as the current study and previous studies (9,37) have reported similar BMI and %BF for recruits at the beginning of the academy. Thus, it is possible that the physical training for the recruits in the current study was significantly different than those in previous studies (9,37) who reported academy-related reductions in body mass.

Cardiorespiratory Fitness

The results of our current study revealed CRF increased from the beginning to the midpoint of the academy, but plateaued from the midpoint to the end of the academy. Previous studies have also reported improvements in CRF across the academy (9,37); however, one study similarly reported an increase for the first eight weeks and then no significant change through week 16 (22). For example, Lan et al. (37) assessed CRF using a 1.5-mile run and indicated a decrease in the median run time (12.2 to 11.0 minutes) at the graduation of academy (week 16), while Cornell et al. (9) assessed CRF using the Forestry Step Test and indicated an increase in both absolute (31%) and relative (28%) VO_2max at the end of the academy. Gnacniski et al. (22) also assessed VO_2max at the first, eighth, and sixteenth week of the academy using the Forestry Step Test. These authors reported a 16.5% increase in estimated VO_2max during the first eight weeks; however, it remained stable during the last eight weeks. It is possible that the lack of significant change between the midpoint and end of the academy in the present study is due increased time spent in the classroom portion of the academy.

Strength and Power

The results of the current study indicated that LE strength improved from the beginning to the end of the academy. Interestingly, non-significant decreases in LF strength across the academy resulted in decreases in the H:Q ratio from the beginning to midpoint of the academy, which then plateaued until the end of the academy. Upper body PF remained unchanged from the beginning to midpoint of the academy, but decreased until the end of the academy. Further, there were no significant changes in VJ performance (average power and jump height) across the academy. Previous studies have evaluated strength and power over the course of a fire academy (9,37). For UB strength, Cornell et al. (9) reported no changes in handgrip strength, but a 9% increase in 1RM bench press strength from week 1 to 14 of the academy. Lan et al. (37) also indicated the median number of 1-minute push-ups and pull-ups increased from 34 to 53 repetitions and 7 to 13 repetitions, respectively. The contrasting findings regarding UB strength in our study and previous literature may be due to the 1) differences in academy training strategies between departments, and/or 2) the unique UB strength assessments (upright row vs handgrip and bench press). For LB strength, Cornell et al. (9) reported 32% increases in lower body strength (estimated 1RM squat) across the academy. These findings are in agreement in our improvements in LE PT. However, these were in contrast to the non-significant decreases in LF PT across the academy that resulted in a decrease in the H:Q ratio. Previous studies have suggested a reduction in H:Q ratio is a significant risk factor for hamstring and/or knee injury (12,61,66). It is possible that a lower H:Q ratio seen at the end of the of the academy may increase the risk of lower body musculoskeletal injuries in firefighters. This information could be relayed to fire administrators to improve training during the academy, specifically to improve LF strength, and in turn, increase the H:Q ratio across academy and decrease the risk of muscle imbalance and potential lower body injuries. Lastly, similar to our findings, Cornell et al. (9) indicated no significant change in jump height or power across the academy. It may be important for future training academies to focus on improving lower body power as previous work has highlighted that power is related to stair climb performance, a occupationally relevant task for firefighters (36).

Injury Risk Factors

The results of the current study indicated that despite no significant changes in movement quality and lower back endurance, balance (composite score, posteromedial reach, and posterolateral reach) performance improved across the academy. Previous literature has reported movement quality, lower back endurance, and balance are injury risk factors in several populations (8,28,38,42); however, studies examining changes across firefighter academies are lacking. Cornell et al. (8) reported improvements in movement quality (composite score and rotary stability) from the beginning to the end of a 14-week training academy using the Functional Movement Screen, however, the deep squat did not change across the academy. The current study assessed movement quality with both a double leg and single leg squat and also reported no significant change. The lack of improvements in movement quality may be due to the lack of squatting movements during both physical and fire-specific training. Although we are unaware of any previous studies examining low back endurance across the fire academy, many previous studies have demonstrated the Biering-Sorenson test is sensitive in detecting nonspecific lower back pain in symptomatic and asymptomatic subjects (38,40). The lack of change in lower back endurance in the current study may be explained by lack of a training specifically targeting lower back endurance. For example, Mayer et al. (40) demonstrated a biweekly 24 week exercise program targeting the core (4 exercises: cat camel, birddog, curl-up, side bridge) and back (1 back extension exercise: variable angle Roman chair) in addition to the already prescribed fire department exercise program improved lower back endurance and reduced lost work time related to lower back pain. Previous studies (42,47) have also suggested balance may impact musculoskeletal injury rates in firefighters. Interestingly, the results of the current study suggest the fire academy training positively impacted the modified star excursion balance assessment. These changes may be explained by increases in LE strength, as previous work has reported isometric LE strength is related to better balance performance (42). Taken together, movement quality, lower back endurance, and balance performance are important predictors of firefighter injuries and could provide fire administrators important feedback to improve future academies and target key firefighter injury risk factors in recruits.

Simulated Occupational Performance

In the present study, stair climb performance improved from the beginning to the midpoint of the academy, but no significant changes were seen between the midpoint and end of the academy. A few studies have evaluated firefighting specific task performance and physical fitness (35,65); however, no studies have reported changes in stair climb performance across the academy. Previous studies (35,51) in firefighters have suggested a number of fitness and muscle-specific variables are related to stair climb performance. For example, Kleinberg et al. (35) reported that both lower body muscle size and quality were independent predictors of stair climb performance. Further, previous literature has reported stair climb performance is related to CRF (13,39,64), body composition (51,64), power (51), and LE PT (51,64). The improvement in stair climb performance in the current study may be due to the improvements in body composition, CRF, and/or LE strength across the academy.

CHAPTER V: SUMMARY

Prior to becoming a career firefighter, recruits must successfully complete a fire training academy. The academy consists of a classroom education portion as well as an on-the-job skill training period. To better understand how the training academy influences key risk factors for fatal and non-fatal injuries and predictors of performance, future work is needed to comprehensively examine changes throughout the academy. Thus, the purpose of the present study was to examine health, fitness, and simulated performance in firefighter recruits at the beginning, mid-point, and end of the firefighter training academy. Nineteen (1 female) career firefighter recruits (mean ± SD; age (yrs) 24.9 ± 4.3; stature (cm) 178.9 ± 7.63 body mass (kg) 82.8 ± 13.2; BMI (kg/m^2) 26.7 ± 3.1) were recruited from a local fire training academy and completed three testing visits across the academy (beginning, mid, end). At each visit, the recruits completed assessments of their body composition (fat mass [FM], fat free mass [FFM], body fat percentage [%BF], body mass [BM]) using a modified 4C model, balance (composite score, anterior reach, posteromedial [PM] reach, posterolateral [PL] reach) using the modified star excursion balance test, movement quality, and countermovement jump (average power, jump height). After taking a short rest period and consuming a standardized breakfast shake, the recruits completed the following assessments: cardiorespiratory fitness (CRF) using a single stage treadmill-based protocol, upper body strength (PF) and lower body strength (leg extension peak torque [LE PT], leg flexion peak torque [LF PT], hamstrings to quadriceps [H:Q] ratio) using isometric dynamometry, lower back endurance, and weighted stair climb (SC) performance. Separate one-way repeated measures analysis of variance (ANOVA) analyses and effect sizes (η^2) were used to examine potential changes of all health and fitness variables during the training academy. When appropriate, follow up analyses included Bonferroni post hoc pairwise comparisons. Main effects for time were revealed for 4C model evaluating body composition (FM, FFM, %BF; $P \leq 0.001$; $\eta^2 = 0.331 – 0.670$), several balance variables (composite score, PM reach, PL reach; $P = 0.006 – 0.011$; $\eta^2 = 0.234 – 0.259$) estimated VO_2max ($P < 0.001$, $\eta^2 = 0.672$), UB PF ($P = 0.010$, $\eta^2 = 0.277$), LB strength (LE PT, LF PT, H:Q ratio; $P \leq 0.027$; $\eta^2 = 0.225 – 0.466$), and the SC ($P < 0.001$; $\eta^2 =0.487$), but not BM ($P = 0.576$; $\eta^2 = 0.032$), anterior reach ($P = 0.312$; $\eta^2 = 0.066$), movement quality ($P = 0.051$; $\eta^2 = 0.161$), VJ (average power, jump height; $P = 0.094 – 0.356$; $\eta^2 = 0.059 – 0.130$) or lower back endurance ($P = 0.394$, $\eta^2 = 0.050$). These results suggest that the firefighter training academy improved several health and fitness variables (body composition, balance, CRF, LE strength) and simulated task performance (SC) across the academy. However, some variables declined (UB strength and H:Q ratio) or were not significantly influenced by the training academy (movement quality, vertical jump performance, lower back endurance). These results are impactful because they can provide fire administrators with information regarding the influence of the fire training academy on key risk factors for the most common fatal and non-fatal injury risk factors and predictors of job performance in firefighters.

Table 1. The mean ± SD values for all variables at each time point (n = 18).

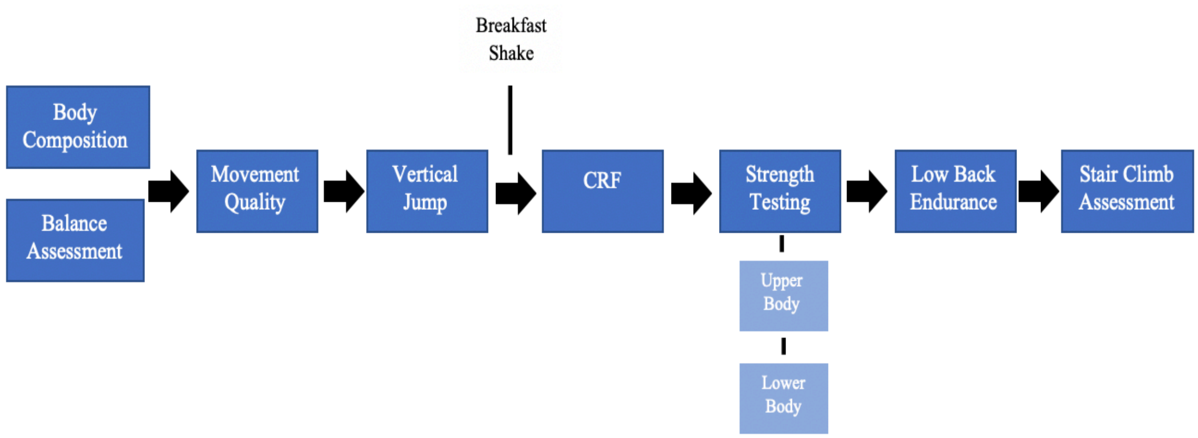
Variable	**Beginning**	**Mid**	**End**
Fat Mass (kg)	14.6 ± 7.0	15.0 ± 6.2	12.5 ± 7.0*†
Fat Free Mass (kg)	68.3 ± 9.1	67.5 ± 8.9	70.6 ± 8.4*†
Body Fat (%)	17.0 ± 6.8	17.7 ± 5.5	14.4 ± 6.6*†
Body Mass (kg)	82.9 ± 13.6	82.5 ± 13.4	83.1 ± 13.6
Normalized Composite Score	2.4 ± 0.3	2.6 ± 0.3	2.6 ± 0.3*
Normalized Anterior Reach	0.6 ± 0.1	0.6 ± 1.0	0.6 ± 0.1
Normalized Posteromedial Reach	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1*
Normalized Posterolateral Reach	0.9 ± 0.1	1.0 ± 0.1‡	1.0 ± 0.1*
Movement Quality (a.u.)	82.0 ± 9.0	79.1 ± 8.6	76.0 ± 6.7
Average Power (W)	1164.1 ± 208.7	1177.3 ± 201.7	1202.9 ± 216.0
Jump Height (cm)	49.5 ± 7.5	49.0 ± 5.9	50.7 ± 7.1
Estimated VO2max (ml/kg/min)	52.6 ± 5.2	56.5 ± 5.1‡	55.7 ± 5.5*
Upper Body Peak Force (N)	821.9 ± 112.3	813.9 ± 100.0	780.9 ± 113.0*†
Leg Extension Peak Torque (Nm)	224.5 ± 47.0	248.5 ± 57.1	255.3 ± 58.8*
Leg Flexion Peak Torque (Nm)	133.9 ± 31.9	121.3 ± 35.0	118.5 ± 35.7
Hamstrings-to-Quadriceps ratio	0.6 ± 0.1	0.5 ± 0.1‡	0.5 ± 0.1*
Lower Back Endurance (sec)	133.0 ± 48.4	124.3 ± 44.1	132.7 ± 41.4
Stair Climb (sec)	70.3 ± 7.7	65.9 ± 7.0‡	64.3 ± 7.2*

‡ $P < 0.05$, significant difference between the beginning and midpoint of the academy

† $P < 0.05$, significant difference between the midpoint and end of the academy

* $P < 0.05$, significant difference between the beginning and end of the academy

Figure 1: Schematic representation of the order of testing. The body composition and balance assessments were performed at random prior to the movement quality assessment.



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